

**H**ERE is a practical, low-cost way to build your own electronic music system. The "Music Modules" presented here are a series of snap-together blocks that let you build any instrument you want, of any desired complexity, using virtually any system architecture you can dream up. Like traditional organ circuits, the system can be equally tempered and fully polyphonic, and it generates up to 97 notes simultaneously with extreme, permanently tuned stability.

As with some synthesizers, the Music Modules give you a wide range of control over the attack, sustain, fallback, decay, snubbing, bite, and echo of a note. As an option, you can have complete control over glides, slide, and portamento effects in either single or multiple voices. The system is economical enough to permit you to make simpler things like pitch references, calliopes, computer music interfaces, composers, and sideman rhythm mates.

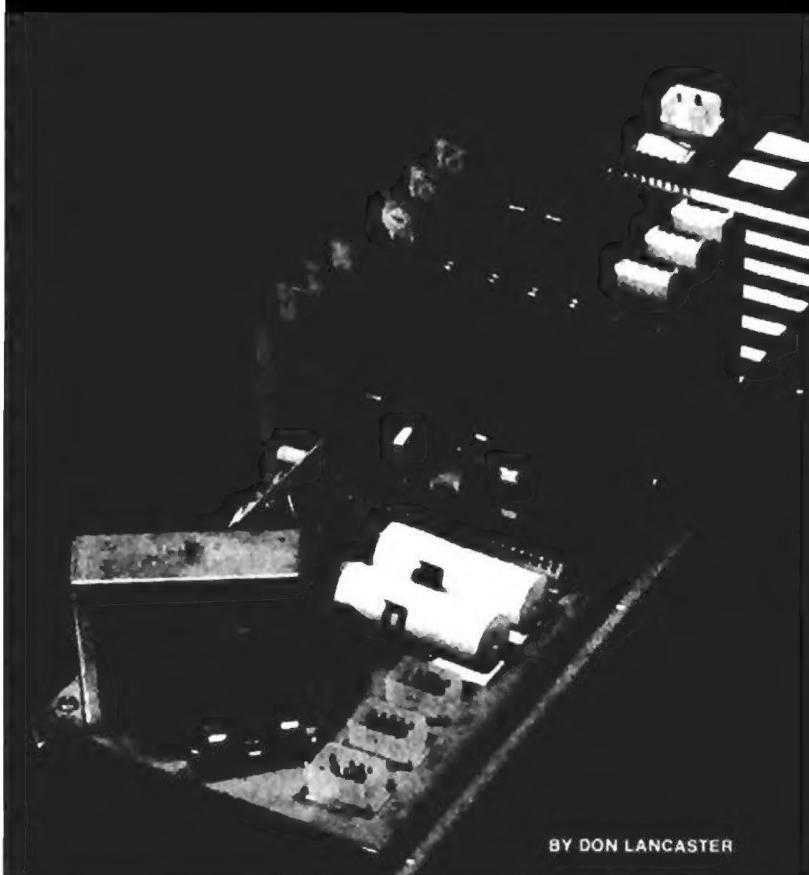
The basic system is composed of three modules: a top-octave generator and translator, a sawtooth divider, and a dual hex vca (voltage-controlled amplifier). You can combine as many of these modules as you want with a power supply and professional keyboard to form the heart of any instrument. What we have here, in effect, is the usually difficult-to-build and expensive repetitive circuit that is the core of any quality polyphonic system reduced to a few simple CMOS circuit blocks.

**Some Basics.** The top-octave generator schematic diagram is shown in Fig. 1. It starts with a 2.000-240-MHz crystal for single, fixed tuning. If you want to tune another instrument, do glides or vibrato, or add noise or other frequency-modulation effects, you can break the oscillator's output circuit and add a variable master pitch reference. A seven-stage binary divider follows the oscillator to reduce the octaves down the scale.

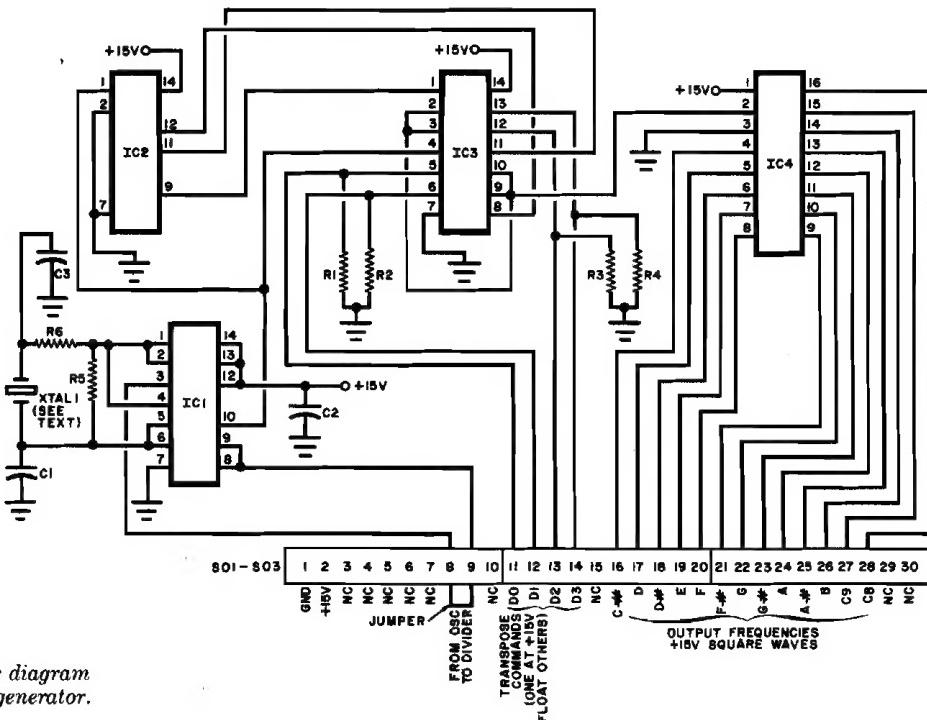
Four possible frequencies are selected from the divider by an electronic switch. These are the crystal frequency and one-half, one-quarter, and one-eighth of the crystal's frequency. The selected frequency goes to a special IC that automatically develops all the notes of the top octave. With the electronic selector switch, you can choose the top octave, which means you can use a short keyboard and only a few vca modules and still be

# MUSIC MODULES

## TO BUILD YOUR OWN SYNTHESIZER



BY DON LANCASTER



*Fig. 1. Schematic diagram of the top-octave generator.*

#### PARTS LIST

**Top-Octave Generator & Translator**  
 C1, C3—27-pF mica or polystyrene capacitor  
 C2—0.1- $\mu$ F, 50-volt Mylar capacitor  
 IC1—CD4001 CMOS quad NOR gate IC

IC2—CD4024 7-stage CMOS binary divider IC  
 IC3—CD4016 quad CMOS switch IC  
 IC4—MK5024P-AA integrated circuit  
 R1 through R4—100,000-ohm, 1/4-watt resistor  
 R5—10-megohm, 1/4-watt resistor

R6—10,000-ohm, 1/4-watt resistor  
 SO1 through SO3—10-contact Molex No. 09-52-3153 connector  
 XTAL—2,000240-MHz parallel-resonant crystal (30-pF load).  
 Misc.—Printed circuit board, hookup wire; solder; etc.

able to generate all the notes you need.

The pitch generator divides the 2-MHz reference 13 different ways to generate the 13 notes of top octave C7 through C8 (2093.01 to 4186.02 Hz). These note divisions approximate the equally tempered music scale with an accuracy better than can be determined by the best musician. Thirteen different references, each one of which corresponds to a different note, are produced simultaneously: C7, C#7, D7, D#7, E7, F7, F#7, G7, G#7, A7, A#7, B7, and, in the next octave up, C8. (For more information on musical pitch, see "Electronic Music Pitch Standards," POPULAR ELECTRONICS, January 1974.)

There are at least two ways to use the top-octave system. In traditional organ architecture, you provide 12 outputs simultaneously and route them to divider modules so that you have all the notes you need all the time. You can also use the translator and an external 1-of-12 selector to generate any single note under digital

command. This is ideal for computer control, pitch references, and many synthesizer applications. Only an on/off keyboard without precision resistors is needed, and the normally troublesome exponential or logarithmic conversion circuitry is built into this module, which is essentially "free" and temperature, time, and voltage stable. All you do is provide a number or digital word to get the note out.

The divider module takes three of the notes of the top octave and generates all equivalent lower-octave notes down to zero (Fig. 2). For instance, suppose one input of one divider module is fed note A7. The outputs of the module will be eight notes (A7 down to A0), each one octave or 2:1 frequency lower in pitch. Each octave output is a square wave, which can be used directly for economy or where you want to imitate "woody" tones (clarinet or stopped organ pipe). The module also contains some resistor networks that convert the square waves into sawtooth outputs. More

precisely, it converts them into a stepped approximation of a sawtooth, but the two are identical once you start to filter them. A sawtooth or its stepped approximation contains nearly all harmonics, compared to a square wave that has only odd harmonics. You can also filter the outputs of this module to recover sine or near-sine waves for flute-like tones.

One top-octave generator and four divider modules are needed to generate all 97 notes either as square or sawtooth waves.

The dual hex vca module provides a means of turning on and off 12 notes combined as two groups of six notes each (Fig. 3). There are several ways you can use this module. Connect the decay bus to -15V, and you obtain simple on/off control of each note without key clicks or other undesirable effects. Grounding a keying input produces a note, while leaving it floating stops the note. Connect the decay bus to +15V, and you get a sharp attack, gradual decay, or long sustain keying characteristic. If you connect

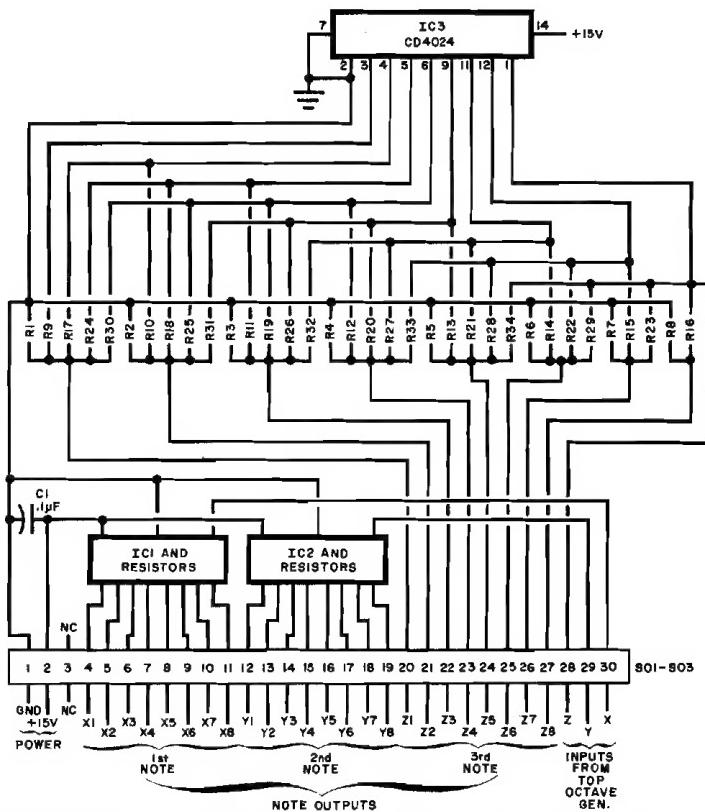
your keying input to a source of controlled-width pulses, you gain complete control of attack, fallback, sustain, and decay of all notes simultaneously, independently and exponentially, with very little added complexity. A storage capacitor on each keying input averages out these control pulses and provides a wide range of independent control of each note.

## PARTS LIST

### Triple Divider Module

C1—0.1- $\mu$ F, 20-volt disc capacitor  
 IC1 through IC3—CD4024 7-stage CMOS binary divider IC  
 The following resistors are  $\frac{1}{4}$ -watt, 10%:  
 R1 through R8, R35 through R42, R69 through R76—220 ohms  
 R9 through R16, R43 through R50, R77 through R84—100,000 ohms  
 R17 through R23, R51 through R57, R85 through R91—200,000 ohms  
 R24 through R29, R58 through R63, R92 through R97—390,000 ohms  
 R30 through R34, R64 through R68, R98 through R102—750,000 ohms  
 SO1 through SO3—10-contact Molex No. 09-52-3153 connector  
 Misc.—Printed circuit board; hookup wire; solder; etc.

*Fig. 2. The divider module takes three of the notes of the top octave and generates equivalent lower-octave notes.*



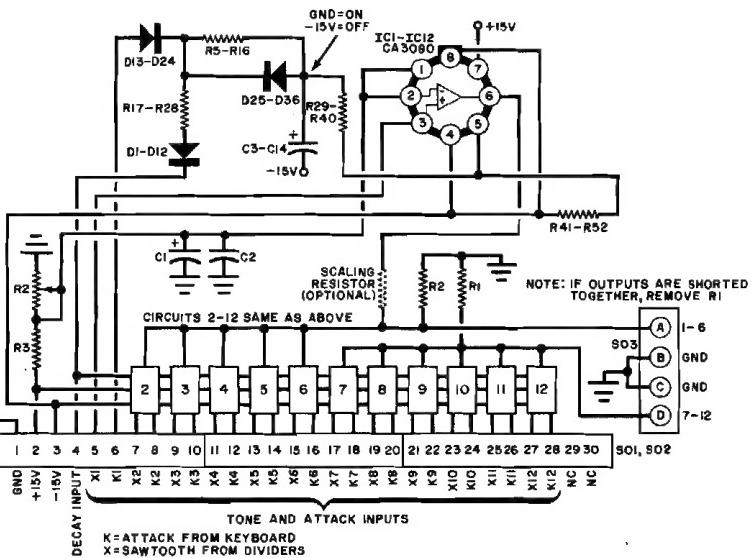
*Fig. 3. The dual hex vca module provides for turning on and off 12 notes combined as two groups.*

## PARTS LIST

### Dual Hex VCA

C1—500- $\mu$ F, 3-volt electrolytic capacitor (14 mm maximum height)  
 C2—0.1- $\mu$ F, 25-volt Mylar capacitor  
 C3 through C14—1- $\mu$ F, 35-volt high-quality electrolytic capacitor with axial leads  
 D1 through D36—IN914 (or similar computer-type) diode  
 IC1 through IC12—CA3080 transconductance amplifier IC (RCA)\*  
 The following resistors are  $\frac{1}{4}$ -watt, 10%:  
 R1, R2—22,000 ohms  
 R3—220,000 ohms  
 R5 through R16—10,000 ohms  
 R17 through R28—3300 ohms  
 R29 through R40—2.2 megohms  
 R41 through R52—680,000 ohms  
 R4—1000-ohm flat-mounting pc potentiometer  
 SO1 through SO3—10-contact Molex No. 09-52-3153 connector  
 SO4—4-contact Molex No. 09-52-3042 connector  
 Misc.—Printed circuit board; hookup wire; solder; etc.

\*There are several different packages available for the CA3080, which fits the TO-5 pin circle shown in the foil pattern. The CA3080S and CA3080E fit 8-pin dual inline minipin patterns. Be sure your pc layout and IC's are compatible. All three package styles remain available from RCA.



Note—The following items are available from Southwest Technical Products Corp., 219 West Rhapsody, San Antonio, TX 78216: No. TOB printed circuit board for top octave generator for \$5.50; complete top-octave generator kit, No. TO-1 for \$17.25; No. TDB pc board for triple divider for \$5.75; complete triple divider kit, No. TD-1, for \$10.50; No. TXb dual hex vca pc board for \$4.75;

complete dual hex vca kit, No. TX-1, for \$21.50; No. TP-1 regulated power supply kit for \$17.50. A fully assembled 37-note professional keyboard designed to AGO standards, No. AGO-37, is available for \$65.00 (includes \$5.00 for handling) from PAIA Electronics, P.O. Box 14395, Oklahoma City, OK 73114. Allow four weeks for delivery.

There are 12 IC's in the vca module. Each controls the gain of a single note. The outputs are normally wired so that six share a common load resistor. However, you can easily break out one or more individual vca's for such things as loudness control, quadraphonic fading, or position modulation, or to introduce tremolo or noise amplitude modulation.

You can use as many vca modules as you want in your system, adding one for each independent, polyphonic octave. Since keyboards are one of the major expenses in any electronic music system, it pays to keep the keyboard as short as reasonably possible. This also cuts down on the number of vca modules you'll need. Remember that you can still get all the notes you want by using the translator switches on the top octave module.

A 72-note polyphonic system, using a 36-note (three octave) keyboard, the top-octave module, four sawtooth dividers, and three vca modules, is shown in Fig. 4. A four-position switch selects which three octaves are to be played at any time. Note that this is only one possible polyphonic arrangement. You can add or eliminate as many parts as you want. In addition, there are all sorts of simpler monophonic variations. A top-octave module and part of a vca module can give you the heart of a synthesizer or a computer-controlled instrument.

**Construction and Checkout.** In the top-octave generator, /C1 is the crystal oscillator and buffer. It is followed by the binary divider in /C2, selector in /C3, and top-octave synthesizer /C4. This circuit should be built on a double-sided pc board, using one side of the board for the foil conductors as in Fig. 5A and the other side for a grounding shield as in Fig. 5B. Component layout and orientation are as shown in Fig. 5C.

Once it is assembled, you can test the top-octave module by connecting to it a 15-volt power supply and jumping pad 8 to pad 9 and pad 2 to pad 11 (foil contacts that mate with the edge connector). Note that only pads 1 and 30 are labelled in Fig. 5C. Then check for the top octave note outputs at pads 16 through 28 using an oscilloscope or audio amplifier. Bear in mind that the outputs consist of 15-volt amplitude rectangular pulses that must be capacitively coupled and strongly attenuated before feeding them into an audio amplifier.

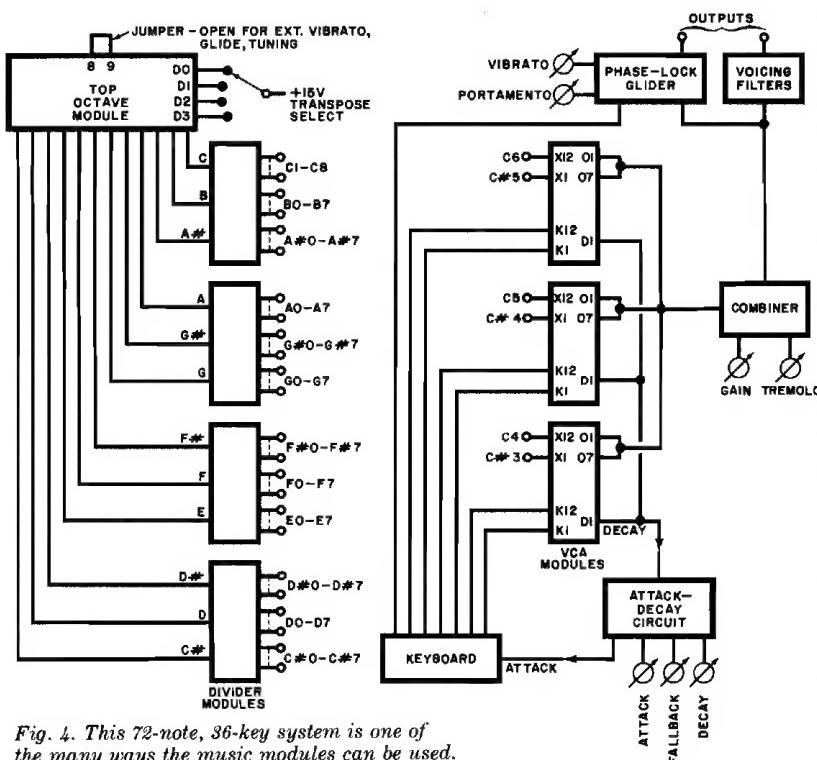


Fig. 4. This 72-note, 36-key system is one of the many ways the music modules can be used.

If you are using the internal oscillator, pads 8 and 9 must be jumpered. For external signals, break the jumper and route a 15-volt CMOS-compatible signal to pad 9. Note also that one and only one of the transpose commands must be at +15 volts at all times; the other three must be floating or grounded.

The foil-conductor etching and drilling, ground-plane, and components-placement guides for the divider

module are shown in Fig. 6. Note that the resistors on this module mount upright.

You can test the divider module by connecting to it a 15-volt power supply and applying three notes from the top-octave generator. The output sawtooth waves should be approximately 70 mV in amplitude (check with a calibrated scope), and each of the three sections of the module should produce eight octave-related notes.

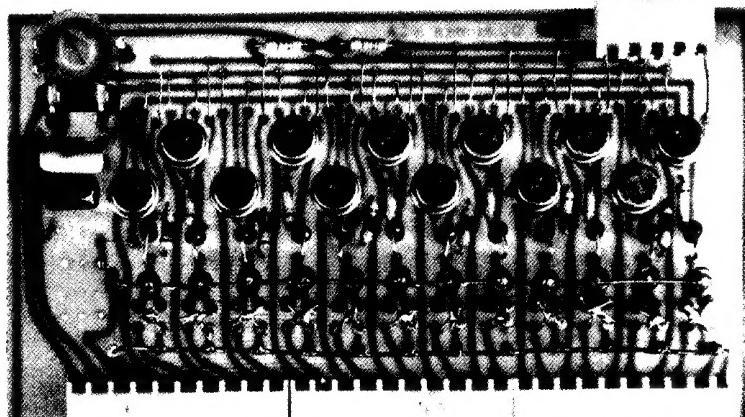
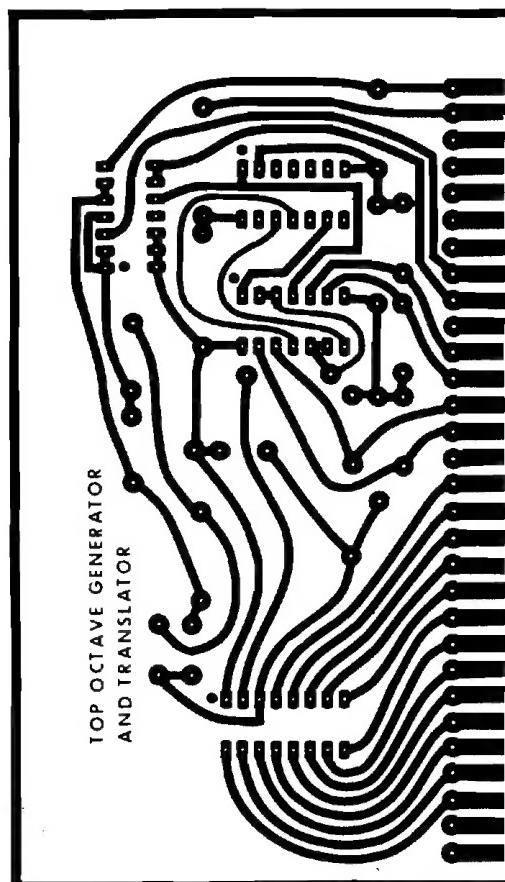
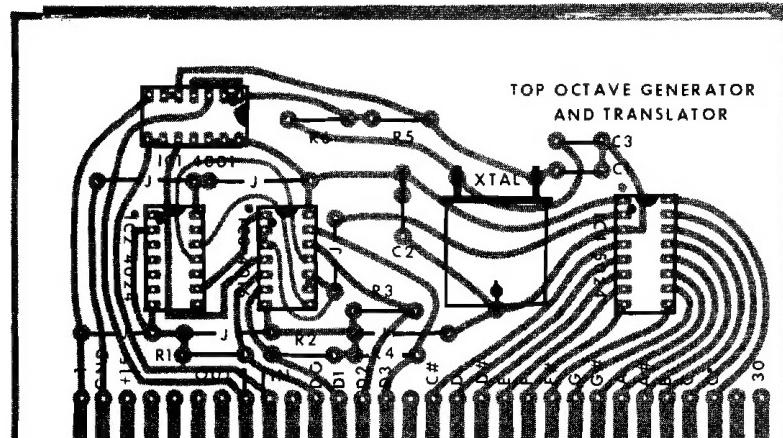
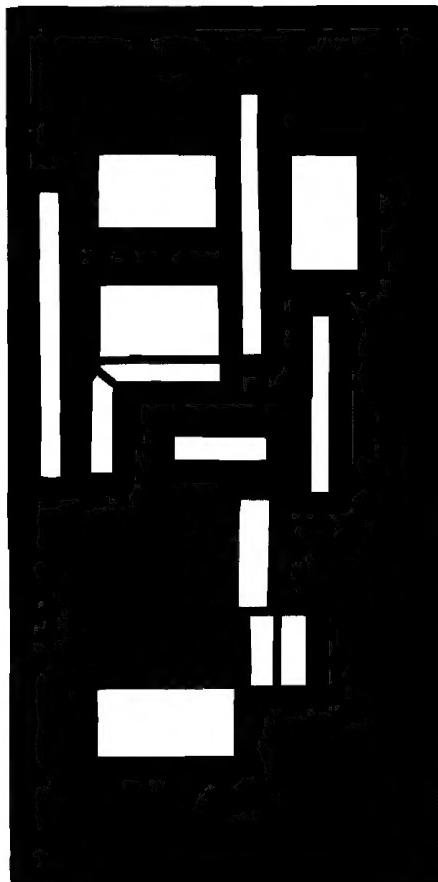


Photo shows details of upright component mounting on vca module and bus connections.



*Fig. 5. Etching and drilling guide (A) for top-octave generator is at left, ground plane guide (B) right, component layout (C) below.*



The highest note will be a square wave, followed by four-level and eight-level notes. Lower-frequency outputs will contain 16 levels. If one note sounds excessively loud or looks wrong on a scope, check your resistor matrix carefully for a missed solder connection or an interchanged value.

The etching and drilling and component-placement guides for the vca module are shown in Fig. 7. Note

that D1 through D12 mount with the cathode (banded) end up and the cathodes to a length of bare wire that terminates in the decay hole. Next, D13 through D36 (cathodes up) and R5 through R28 mount upright, their free ends connected together in groups of four, with D13, D25, R5, and R17 making up the first and D24, D36, R16, and R28 the last group. Then mount C3 through C14 with their negative (-)

leads up and connected to a length of bare wire that terminates in the -15V hole. Finally, mount R29 through R40 in the usual manner, without bus joining the upright leads.

The best way to test the vca module is one stage at a time. Do this by leaving the IC pin 6 jumpers disconnected from the output buses, except for the jumper in the stage being tested. Start by connecting the dual-polarity +15/-15-volt power supply to the module via pads 1, 2 and 3 at the edge connector. Route a single note from the divider to the X1 input and monitor the output with an oscilloscope or audio amplifier. Connect the decay input to -15 volts. Now, grounding K1 should turn on the note and floating or connecting K1 to -15 volts should turn off the note. The note should turn on and off rather abruptly without key clicks, distortion, or transients. Offset potentiometer R4 should be adjusted to eliminate any dc in the output or set for the best sounding note. Then, check K2 and X2, K3 and X3, and so on down the line, finishing up with K12 and X12.

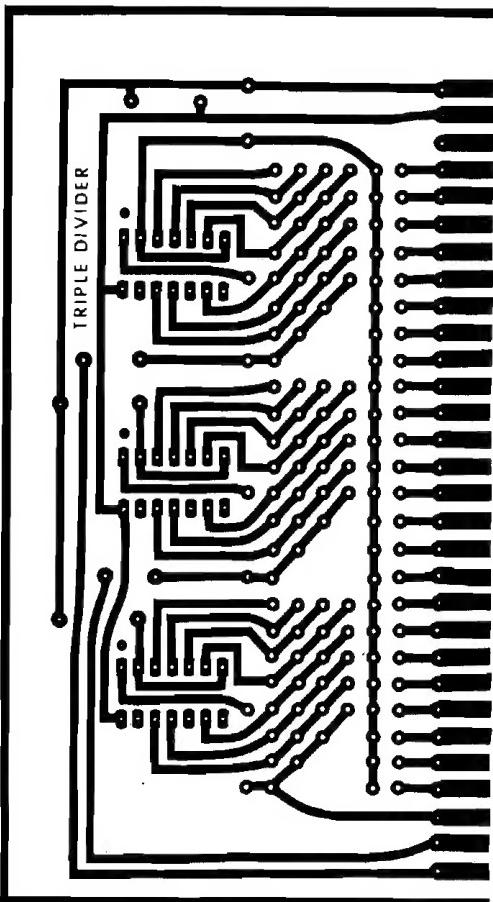
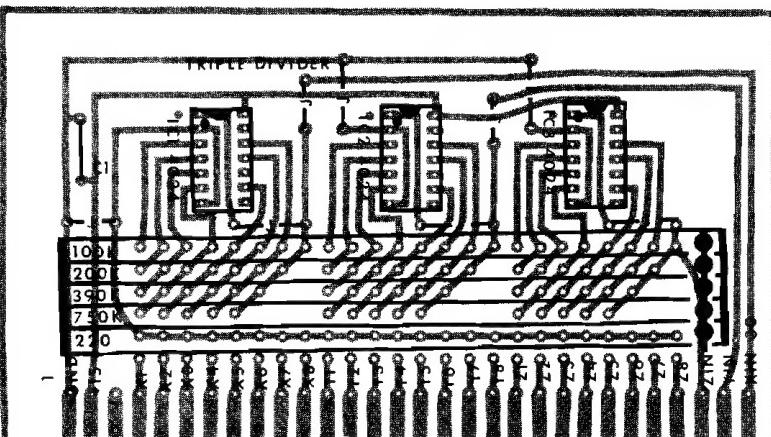
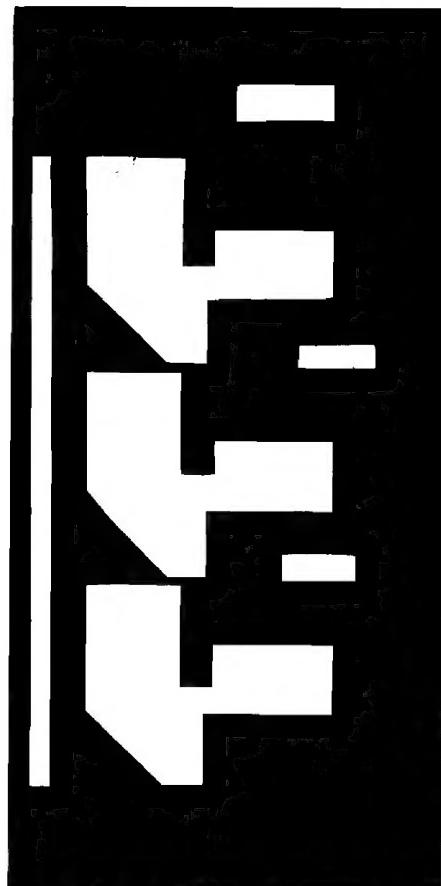


Fig. 6. Etching and drilling guide (A) for triple divider is at left, ground plane guide (B) right, and component layout (C) below.



The CA3080 IC's have a *high-impedance* (current-sourcing and -sinking) output, unlike the other op amps. This permits you to short as many outputs as you wish to a common load resistor to automatically sum all the outputs. The amount of maximum output signal is set by load resistors  $R_1$  and  $R_2$ . If you use both halves of the vca module,  $R_2$  can be omitted.

An open circuit at any X input disrupts the summing process, so be sure that all connected IC's are in fact receiving tones from the divider modules. Connecting the decay input to ground should give you a fast-attack, long-decay characteristic. If any single note sounds odd or responds differently from the rest, check the resistor/diode/capacitor matrix for shorts, incorrect values, or unsol-

dered connections. All diode bands (cathodes) go up as do the negative sides of the electrolytic capacitors.

**System Interconnections.** No matter what arrangement you choose for your instrument, there are some important system-level things you'll have to watch for. First, be sure to use a well-regulated power supply. While CMOS devices will operate on a wide range of low voltages, the +15-V supply contributes directly to the staircases of the note. Hum or noise or interaction on the supply spells problems.

Be sure to use twisted-pair wiring or shielded cable between the top-octave outputs and the dividers to minimize any radiation of these high-level signals. You can put your modules on 20-mm centers, but be sure to skip one slot between the last divider and first vca modules, and place a fairly thick grounded sheet of steel between the two. Proper shielding and lead routing can mean the difference between a solid 85-dB or higher

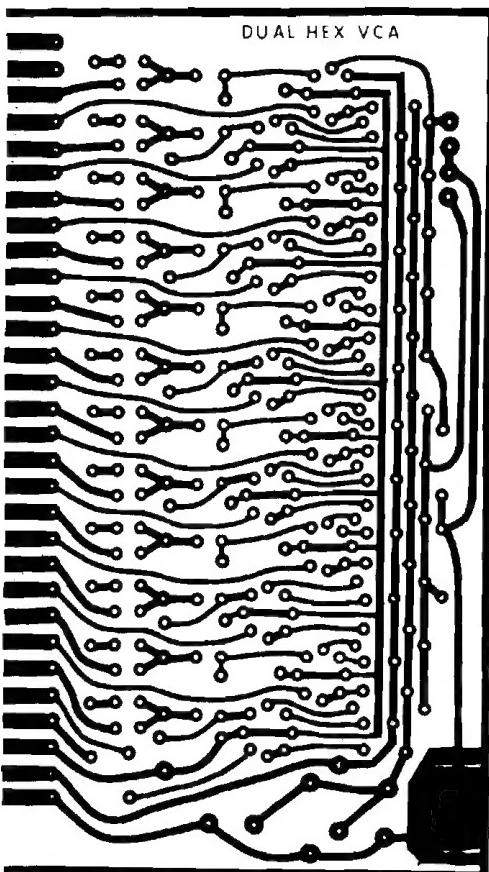


Fig. 7. Etching and drilling guide (A) for vca module is at left, component placement guide (B) at right. No ground plane is required.

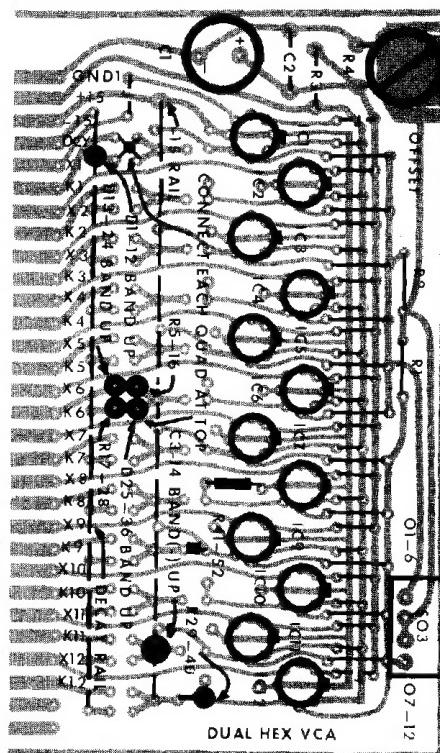
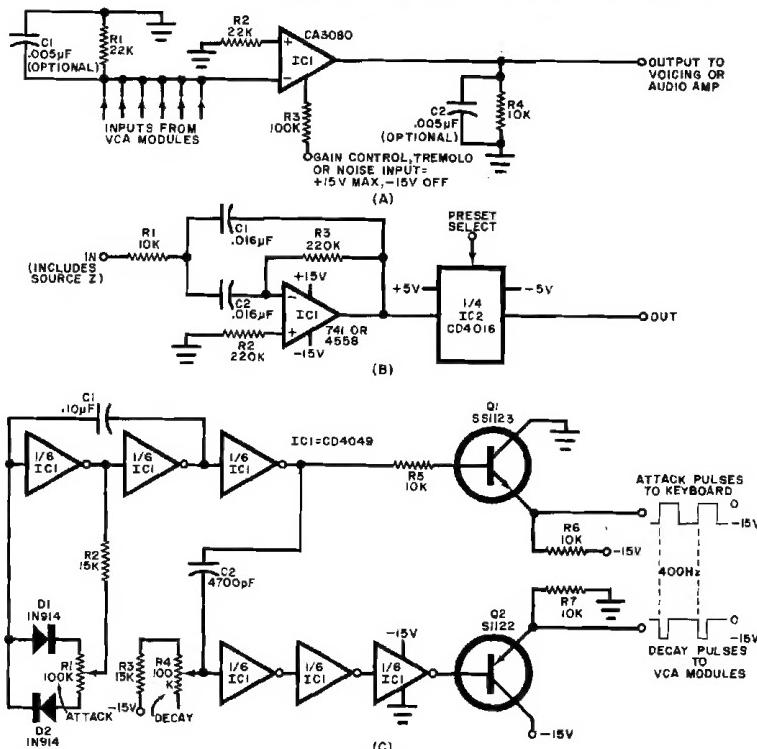


Fig. 8. Add one or more of the circuits below to basic system to build a complete music synthesizer.

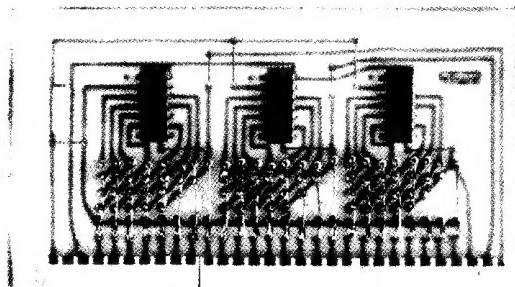
crosstalk and playthrough level and an intolerable 60-dB level.

Shields are also required on the vca module's outputs because of the fairly high impedances involved. Outputs are located on the top of the vca module to keep them well away from the tone-generator signals. The same care you give to the high-level tone signals should also be given to the attack and decay control pulses.

Some add-on circuits that will get you started on your system are shown in Fig. 8. In A, a CA3080 is used as a combiner and master gain control. The outputs of as many vca modules as you want can be shorted together and routed to this stage, but be sure to use shielded cable. Resistor  $R_1$  can be adjusted to maintain the maximum input signal level to 100 mV peak-to-peak with several notes being played simultaneously. A variable voltage ranging from +15 volts (for maximum gain) to -15 volts (for off) will control the loudness of everything in the system. You can also sum a low-frequency sine wave or noise spectrum for tremolo, wind noise, or other



*Photo of divider board shows all resistors mounted upright and bus-connected to socket pads.*



amplitude-modulated effects. Capacitors  $C_1$  and  $C_2$  are optional. Installing them in the circuit yields a mellow sound; eliminating them permits the use of fancy voicing filters in the output.

A horn filter is shown in Fig. 8B. To change the center frequency, change the values of  $C_1$  and  $C_2$ , but keep both capacitor values identical. To change the Q, change the values of the resistors, keeping  $R_2$  and  $R_3$  at  $4Q^2$  times the value of  $R_1$ . Note that  $R_1$  must include the source impedance of the circuit or circuits from which you are tapping the signal.

You can simultaneously control the attack and decay of all notes with the pulse-width system shown in Fig. 8C. To do this, you rapidly switch the 10k attack and 3.3k decay resistors in and

out of the vca channel. (A 10k resistor in the circuit at all times has an effective value of 10,000 ohms. If it is in the circuit only 10% of the time, its effective value is 100,000 ohms.)

The circuit employs a single CMOS hex inverter and a pair of drive transistors. The attack portion is a variable-duty-cycle oscillator that operates at 400 Hz. The length of time that the attack remains grounded determines the attack time as a ratio of the total time. If you end up with too much interaction between frequency and duty cycle, a high-value resistor across one of the diodes should fix things. The frequency should remain nearly the same as you change the duty cycle.

The leading edge of the attack waveform can be shortened by operating DECAY potentiometer  $R_4$  and

capacitor  $C_2$ . It is then amplified and routed to the decay inputs of the vca module. Note that attack goes to the keyboard, while decay goes to the vca's. The attack time has priority over decay, so a key fully pressed charges the vca capacitor that is storing the attack and decay information. Because of the resistor values in the vca circuit, up to a 3:1 reverse attack can be accommodated at the extremes of the control settings.

A second decay circuit connected to a driver transistor that catches at some negative voltage will provide fallback. This is important for percussion voices that simulate piano and guitar effects. With fallback, the note very rapidly decays to some low value when the key is released. It then gradually dies out.

**Final Comment.** With the three basic music module blocks we have presented, plus a keyboard, you have the heart of a sophisticated electronic music synthesizer. You can put add-ons into the system and modify it to suit your needs. In fact, you can expand it until you have a highly sophisticated and flexible polyphonic instrument. ◇